MULTIMEDIA UNIVERSITY

STUDENT ID NO

MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 2, 2019/2020

ENT4046 – N/MEMS

(NE)

04 MARCH 2020

2.30 p.m. – 4:30 p.m.

(2 Hours)

INSTRUCTIONS TO STUDENTS

1. This Question paper consists of 5 pages with 4 Questions only.
2. Attempt **ALL FOUR** questions. The distribution of the marks for each question is given.
3. Please print all your answers in the Answer Booklet provided.
4. Please refer to page 4 and 5 for the List of Formulas and the Appendix.

QUESTION 1

(a) Compare the differences between microelectromechanical system (MEMS) and microelectronics on the three key characteristics as shown in **Table 1(a)**.

Table 1(a)

	MEMS	Microelectronics
1. Function		
2. Structure		
3. Manufacturing		

[6 marks]

(b) Sketch the block diagrams of (i) *self-generating transduction without parasitic*, (ii) *self-generating transduction with parasitic*, (iii) *modulating transduction without parasitic*, and (iv) *modulating transduction with parasitic*, respectively. Explain briefly the diagrams.

[6+6 marks]

(c) With the aid of a suitable diagram, describe the working principles of MEMS used in the automotive airbag system.

[3+4 marks]

QUESTION 2

(a) Sketch the plot of *instantaneous position of mass*, $X(t)$, as a function of *time*, t, for the five following types of mass-spring vibration, respectively. Explain briefly each of the plot.

- Free vibration
- Overdamped vibration
- Critically damped vibration
- Underdamped vibration
- Forced vibration

[5+10 marks]

(b) **Figure Q2(b)** shows a silicon (Si) cantilever beam-mass type microaccelerometer. The Si beam has a Young's modulus of 190 GPa. Answer the following:

(i) Calculate the stiffness of the beam.

[5 marks]

(ii) Calculate the deflection of the beam if a force of 15 μN is loaded to the end of the beam.

[2 marks]

(iii) Calculate the damping coefficient if the beam is submerged in a non-compressible damping fluid.

[3 marks]

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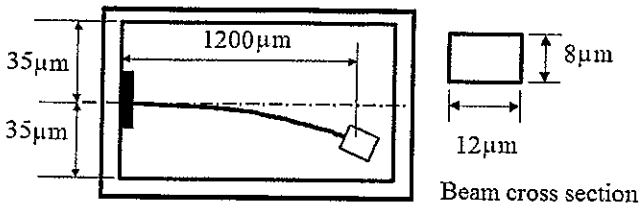

Figure Q2(b)

QUESTION 3

(a) A comb drive microresonator with 20 gaps in air was fabricated. Each gap between 2 fingers is 1.5 μm and number of gaps is 20. Answer the following:

(i) Calculate the total capacitance of the comb drive microresonator if the overlapping area is 45 μm × 35 μm.

[3 marks]

(ii) Calculate the total electrostatic force for lateral deflection if the width of the fingers is 45 μm and 75 V is applied.

[3 marks]

(b) Define pull-in voltage of parallel-plate capacitor. What is the distance for a gap-closing electrostatic microactuator to move reliably?

[4 marks]

(c) (i) Describe briefly the piezoresistive effect.

[2 marks]

(ii) Explain why the resistivity can be changed under the piezoresistive effect.

[4 marks]

(d) A transverse piezoresistor is made of *n*-type single-crystal silicon (Si) with resistivity of 11.7 Ωcm aligned in the <110> direction. Given the Young's modulus of single-crystal Si is 168 GPa in the <100> direction, and the piezoresistor is under strain of 5×10^{-6}. Answer the following:

(i) Calculate the transverse piezoresistive coefficient.

[3 marks]

(ii) Calculate the transverse gauge factor.

[3 marks]

(iii) Calculate the relative change of resistance.

[3 marks]

Continued...

QUESTION 4

(a) Given the rate of heat conduction in solid $Q = qA = -KA\frac{\Delta T}{\Delta x}$, and the varaition of thermal conductivity in solids in submicron regime $K = \frac{1}{3}cV\lambda$, where q is the heat flux, A is the cross-sectional area, K is the thermal conductivity, $\Delta T/\Delta x$ is the thermal gradient, c is the specific heat, V is the group velocity, and λ is the mean free path. Using the relationship $\lambda \propto 1/\rho$, in which ρ is the mass density of solid with an order that is similar to the volume, express the scaling of the heat flow in a solid in the *submicron regime*, and estimate the variations of the heat flow with a reduction of size by a factor of 10.

[3+2 marks]

(b) With aid of diagrams, illustrate the step-by-step process in fabricating the torsional parallel-plate capacitive accelerometer shown in **Figure Q4(b)** begins from a silicon wafer with conducting electrode patches. Label clearly the diagrams.

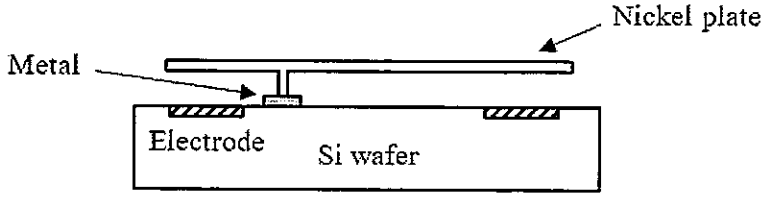

Figure Q4(b)

[10 marks]

(c) Describe briefly in sequence the **FOUR(4)** main processes that are involved in MEMS packaging.

[10 marks]

List of Formulas:

$w_{\max} = -\frac{0.0138pa^4}{Eh^3}$	$\sigma_{\max} = \frac{0.308pa^2}{h^2}$
$w_{\max} = -\alpha\frac{pb^4}{Eh^3}$	$(\sigma_{yy})_{\max} = \beta\frac{pb^2}{h^2}$
$w_{\max} = -\frac{3W(m^2-1)a^2}{16\pi Em^2h^3}$	$(\sigma_{rr})_{\max} = \frac{3W}{4\pi h^2}$
$\delta = \frac{FL^3}{3EI}$	$c = 16f\left(\frac{W}{L}\right)W^3LH_o^3$
$k = \frac{F}{\delta} = \frac{3EI}{L^3}$	$c = \frac{2\mu Lb}{H}$

Continued...

$I = \frac{bh^3}{12}$	$\rho = \frac{2h}{3(\alpha_2 - \alpha_1)T}$
$F = \frac{(\alpha_2 - \alpha_1)T}{8} \frac{hb}{\left(\frac{1}{E_1} + \frac{1}{E_2}\right)}$	$\frac{\theta}{arc(AC)} \approx \frac{\theta}{line(AC)} = \frac{360}{2\pi\rho}$
$\Delta P = Q\left(\frac{8\mu L}{\pi r^4}\right)$	$\delta = \rho - \rho\cos\theta$
$\Delta P = Q\left(\frac{12\mu L}{wd^3}\right)$	$C = \frac{\varepsilon_r \varepsilon_o A}{d}$
$F_d = -\frac{\varepsilon_r \varepsilon_o WLV^2}{2d^2}$	$F_W = \frac{\varepsilon_r \varepsilon_o LV^2}{2d}$ or $F_L = \frac{\varepsilon_r \varepsilon_o WV^2}{2d}$
$k = N\left(\frac{12EI}{L^3}\right)$	$U_P = \sqrt{\frac{8}{27}\frac{kd}{\varepsilon_0 A}^3}$

Appendix:

Table of Interpolation for Numerical Values of the Function f(W/L) Versus W/L.

W/L	0	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.1
f(W/L)	1	0.992	0.984	0.976	0.968	0.960	0.952	0.944	0.936	0.928	0.920

Table of Piezoresistivity Components for Single-Crystal Silicon under Certain Doping Values.

Piezoresistance coefficient (10^{-11}Pa^{-1})	n-type (resistivity = 11.7 Ωcm)	p-type (resistivity = 7.8 Ωcm)
π_{11}	−102.2	6.6
π_{12}	53.4	−1.1
π_{44}	−13.6	138.1

Formula for Transverse and Longitudinal Gauge Factors for Various Commonly Encountered Resistor Configurations.

Direction of strain	Direction of current	Configuration	Piezoresistive coefficient
<100>	<100>	Longitudinal	π_{11}
<100>	<010>	Transverse	π_{12}
<110>	<110>	Longitudinal	$(\pi_{11} + \pi_{12} + \pi_{44})/2$
<110>	<1$\bar{1}$0>	Transverse	$(\pi_{11} + \pi_{12} - \pi_{44})/2$
<111>	<111>	Longitudinal	$(\pi_{11} + 2\pi_{12} + 2\pi_{44})/2$

End of Paper